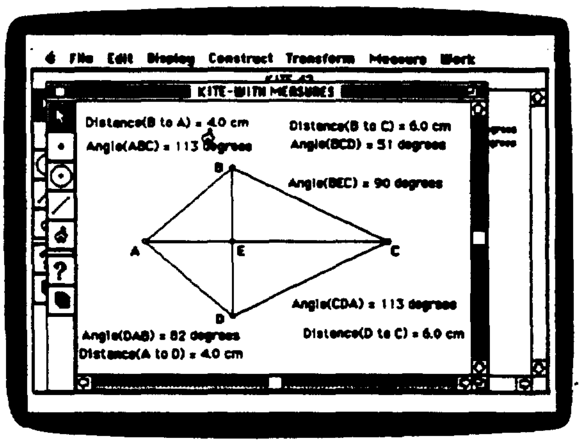
High school students in calculus and algebra classes demonstrate their understanding of math by writing papers explaining mathematical concepts in real-world situations, using *Mathematica* to execute the examples they've created.

High School Mathematics

Why use computers in high school mathematics instruction?

As a tool in mathematics classrooms, the computer helps students understand abstract concepts by making them visual and manipulable. Students can own complex ideas by manipulating algebraic formulae and constructing geometric figures. They can study phenomena, not merely techniques. Students become active learners: they identify "interesting" behavior, explore the conditions under which it occurs, analyze their observations, and interpret their results. Students can *do* mathematics and be engaged in creative problem solving.



Students can manipulate the characteristics of geometric shapes and ask "What-if?" questions using The Geometer's Sketchpad *from Key Curriculum Press.*

Technology-rich curricula reduce the time students routinely devote to practicing skills and manipulating symbols out of context. With simulations and models in geometry (or, for that matter, in algebra, trigonometry, and calculus), students can pursue questions of why, when, how, and "What-if?". As the National Council of Teachers of Mathematics notes, "The new technology has changed the very nature of the problems important to mathematics and the methods mathematicians use to investigate them."

What the research shows:

Students who use computers in math have more positive attitudes about themselves as mathematicians and about math in general, and show significant gains in problem-solving ability and content knowledge. [1]

Computer software that encourages student exploration supports instruction that increases students' understanding of mathematics principles. [2]

Students who work in small groups on geometry problems showed improvement on higher-level problem solving and applying math applications; they also received significantly higher scores on standardized final exams. [3]

High School Mathematics

Students using computers for algebra did significantly better on a test of knowledge than did a group taught by traditional methods. The computer group also retained more of the information and scored significantly higher on measures of transfer to other areas of mathematics.[4]

Citations for research results:

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Places to call or visit:

Jim Nazworthy, Physics Teacher, John Biggerstaff, Math Teacher, Lee's Summit High School, 400 East Blue Parkway, Lee's Summit, MO 64063, 816/524-7151

Mike Froning, Faculty Chair, Alabama School of Fine Arts, 700 18th Street North, Birmingham, AL 35203, 205/328-3143

Wayne Robinson, Principal, Sandy Creek High School, 360 Jenkins Road, Tyrone, GA 30290, 404/969-2842

Media Fusion

Preface

This investigation is one of Apple Classrooms of Tomorrow's experimental projects focused on building new technologies and understanding their effects on learning and teaching.

Site

Davidson Middle School, San Rafael, Calif. A second school to be selected.

Funding

Apple Computer, Inc. and the Public Broadcasting Corp.

Research Partners

Rick Borovoy ACOT Media Fusion project manager; Gina Funaro, ACOT external project manager; Chris Hancock of Technical Education Research Centers; Molly Breeden and Mark Richer of PBS, and school districts.

Learning Issue

Television is pervasive and excels at telling timely, captivating stories, but it is limited by its lack of depth and interactivity. Computers offer interaction, explorable environments and ways to exchange information but they are less common and in many cases difficult to use. We will study new ways of learning that combine timely televised stories with explorable computer models.

Research Focus

We believe television and computers are perfect complements. With PBS, we are examining the learning potential of fusing the two technologies. We will use television news clips to make current, complex issues relevant to students. The news reports will be extended with data and powerful analysis tools. The curriculum will have students analyze this data and create their own perspectives on the news. We will provide ways for students to share their perspectives with other students and will examine whether the opportunity to influence an audience of one's peers at other schools around the country will motivate students to think critically and explore deeply. We will investigate how these factors can create an environment where students perform self-directed, complex inquiry into important issues and discuss their discoveries.

Technology Development

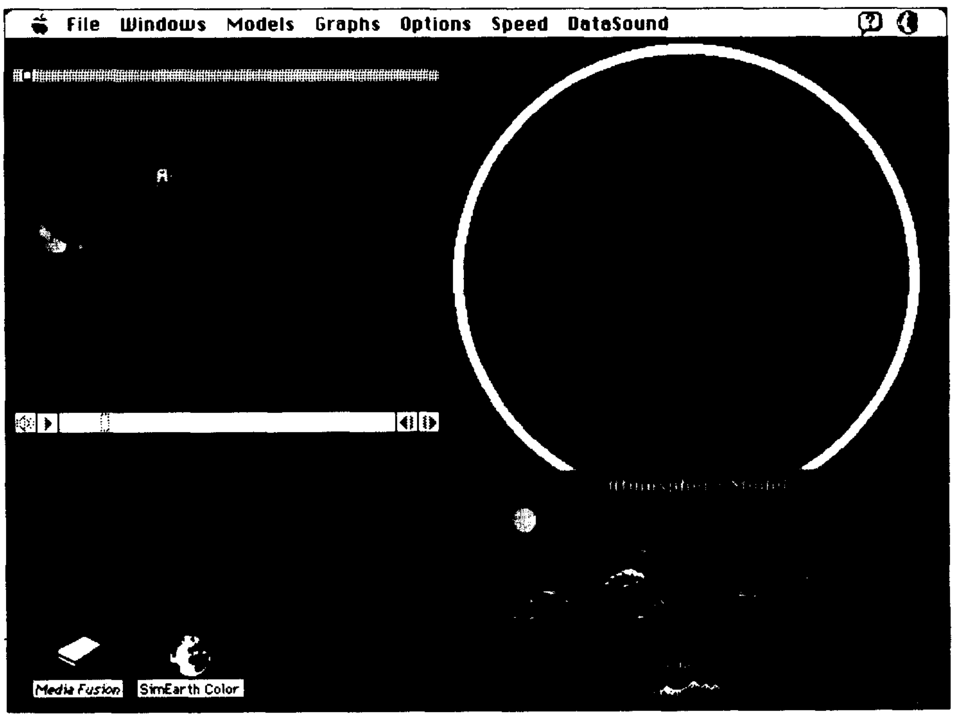
We are developing prototype software mechanisms for efficiently encoding, embedding, and distributing active links between traditional communications media, such as text or video, and a large class of dynamic modeling environments including simulation and visualization tools. These links will work over a network. What is transmitted isn't simply the author's final analysis but all the steps of the author's discovery, allowing recipients to effortlessly explore both.

Curriculum Construction

Students will have a constant and timely stream of enhanced versions of news stories from the PBS MacNeil/Lehrer program, embedded with links to computer models. For example, while a student watches a news clip about global warming and the destruction of the Amazon rain forest, the computer would automatically set up an environmental simulation that reflects the content of the televised discussion. Students could then explore the dynamics of the "greenhouse effect," make their own discoveries and decisions. Based on their findings, students will create their own video Media Fusion stories, and broadcast them to other students via a PBS satellite network.

Research Findings

Our research in schools will be begin in late 1992.



Here, MacNeil/Lehrer's Judy Woodruff introduces a news story about global warming. Then students experiment with the relationship between the greenhouse effect and atmospheric temperature, using an environmental simulation.

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Cupertino, Calif. 95014
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Wireless Computing and Scientific Inquiry

Preface

This investigation is one of Apple Classrooms of Tomorrow's experimental projects focused on building new technologies and understanding their effects on learning and teaching.

Site

Sabino Canyon, Tucson, Arizona, with students and teachers from Orange Grove Middle School, Tucson, Arizona

Funding

Apple Classrooms of Tomorrow and Orange Grove Middle School

Research Partners

Wayne Grant, ACOT "Wireless Coyote" project manager; Rick Borovoy, ACOT engineer, and Brian Reilly and Cathy Ringstaff Ph.D., independent researchers.

Learning Issue

Wires, size, and power demands immobilize desktop computers preventing teachers from re-arranging technologies to accommodate different learning needs, spatial organizations, and learning contexts. Mobile, wirelessly connected computers could bring networked computer processing to a wider range of learning situations, thereby offering the flexibility teachers need to design computer-supported, collaborative learning experiences in more authentic learning contexts.

Research Focus

We developed tools to help students construct data-driven hypotheses that lead to on-the-spot collaborative investigations outdoors. We investigated the social, technological and task issues of collaborative computing when teachers and students used wireless, mobile computers on a science field trip, called "Wireless Coyote."

Radio waves carried data so students could receive different perspectives of the canyon.

Developme

Technology Development

We created a wireless computer by fastening a spread spectrum, radio frequency modem and batteries to a pen-based, notebook computer. We built a collaborative spreadsheet for sharing data in real-time across a wireless network and a graphing tool to provide different perspectives on the data. (Walkie-talkies were also used by students for communication.)

Curriculum Construction

The mobile, wireless network enabled students to collect, analyze, share, and compare environmental data in real time in the canyon. This allowed teachers to foster discussions of the analyzed data within and between groups and to develop with students, data-driven hypotheses that lead to on-the-spot collaborative investigations.

Learning Research

Findings	Limitations
Students saw hypotheses are not only validated or invalidated by analysis, but often they arise during collaborative assessments of data that depict the same aspects of an environment from multiple perspectives.	The software supported data sharing, but the interface did not adequately address the problem-solving needs of collaborating groups. The data table was difficult to navigate, and obscured views of data received from other groups.
The networked supported a collaborative approach to science.	The tasks did not naturally demand collaboration between and within groups, requiring teachers to trigger most collaborative interactions.
Some students analyzed data, and actively transformed it to reveal patterns and relationships. They understood the canyon, and described it using terms and concepts expert scientists use.	Limited numbers of computers reduced the potential impact of the collaborative, science experience.

The mere presence of a collaborative medium, or an expectation of collaboration, will not insure its appearance. All dimensions of the situation – physical, social, task, and technology – must be carefully designed to increase the frequency and effectiveness of collaborations. The first study was in May, 1991. A second is under development.

A collaborative spreadsheet and graphing tool spurred on-the-spot data analysis

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Hands On Data

Preface

This investigation is one of Apple Classrooms of Tomorrow's experimental projects focused on building new technologies and understanding their effects on learning and teaching.

Site

The Fletcher School, Cambridge, Massachusetts - grades 5-8.

Funding

The National Science Foundation and Apple Computer, Inc.

Research Partners

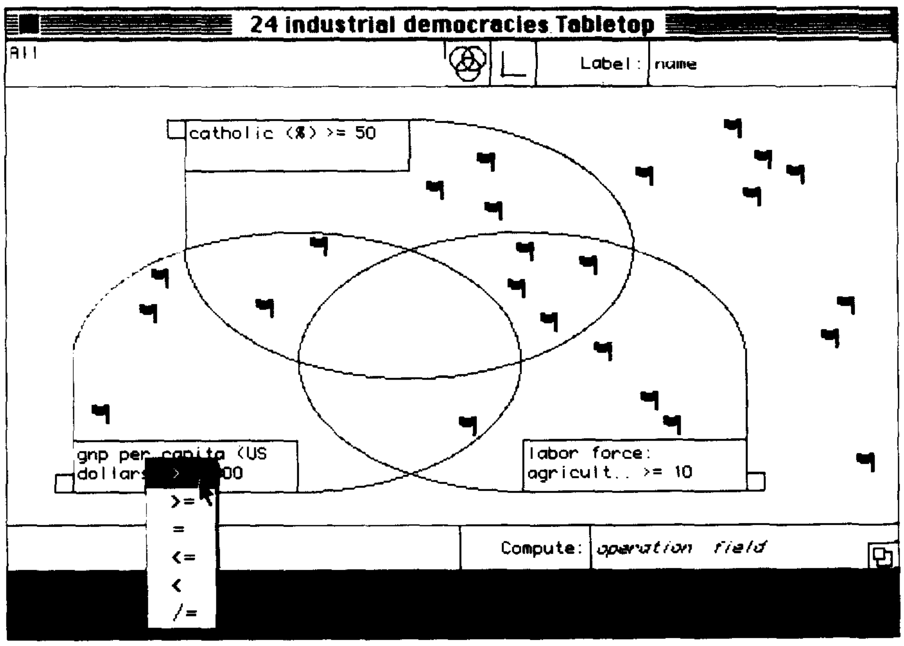
Chris Hancock, Technical Education Research Centers; Lynn Goldsmith, Education Development Center; teachers Bill Caragianes, Edward E. Rice and Joan Lachance; Gina Funaro, ACOT external project manager.

Learning Issue

Society relies on data and mathematics to understand and discuss vital issues. However, students often lack the skills required to use data to solve real problems and rarely develop an appreciation of mathematics as a way of understanding the world.

Research Focus

We want to know how to use authentic inquiry to develop data modeling and mathematical skills in young students.



This model of industrialized nations can be instantly restructured by choosing any constraint shown. Affected icons move to new positions.

Developme

Technology Development

Tabletop is a unique database environment for young students. Tabletop provides a row and column view in which to define fields, and enter and edit data. Tabletop also features an animated, iconic view of data. One icon appears in a window (or "tabletop" view) for each record in the database. By looking at patterns these icons make, students can learn about a whole data set. And, by imposing constraints on these icons, students can reveal hidden properties of the data set. For example, if a student enters a mathematical constraint, such as "population > 500,000," the icons become animated and move on the computer display to satisfy that constraint. With Tabletop students can examine individual records and array icons as scatter plots, histograms, Venn diagrams, and other graphs to explore more general trends.

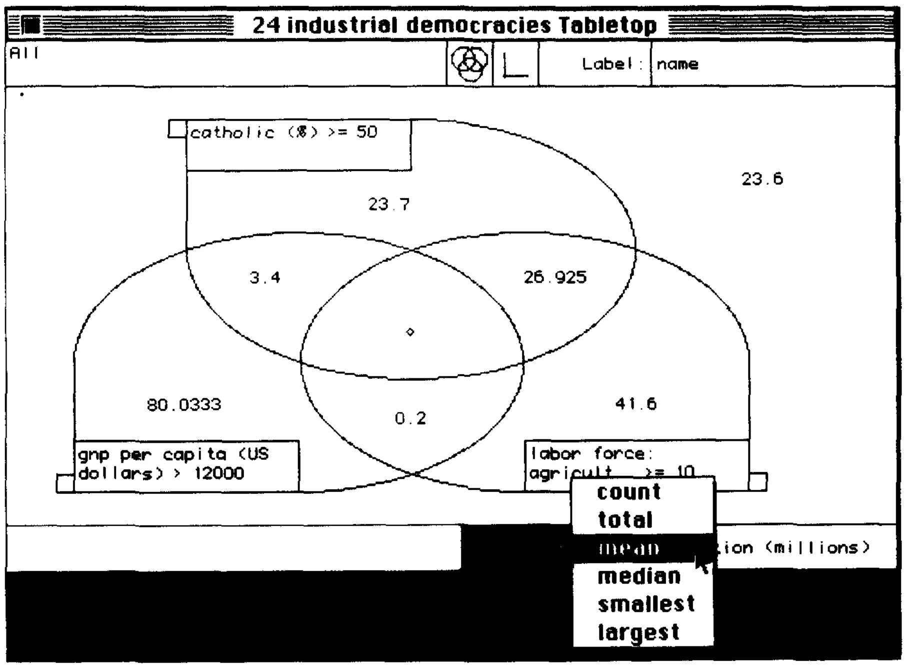
Curriculum Construction

We created seven interdisciplinary units that require students to collect, structure, analyze real-world data, and present findings to their peers. Although the curriculum is driven by issue-oriented projects, statistical concepts such as mean, trend, correlation and sampling are at its heart.

Research Findings

We identified several obstacles to classroom implementation. For example, although classroom activities often related to a general theme they were not sufficiently coordinated to move students towards a specific goal. Consequently, students did not understand the larger problem they were trying to solve and how each activity helped solve it.

We identified limitations in skills students had when they analyzed data to answer specific questions. Our observations and interviews revealed that students often focused on individual cases and had difficulty looking beyond the particulars of a single case to make generalizations about the group as a whole. For example, although students knew how to compute the mean, they lacked the ability to use that information to interpret and reason. Their inability to construct such representative values for groups, seriously limited their ability to model data. The research work in progress is investigating students' understanding of basic data structure concepts – the challenges students face in learning to translate real world situations into the record/field structure of most databases.



This is a mean population of each of the eight subgroups created by the Venn diagram.

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20525 Mariani Avenue
Cupertino, Calif. 95014
(408) 862-5134

All ACOT information available on-line via AppleLink (pathway: K-12, Education Resources, Apple Education Research, Apple Classrooms of Tomorrow) or on America On-Line in the "ACOT conference room" and via ERIC, the Dept. of Education database available at libraries.

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Partnerships for Change

Author

Jane L. David Ph.D.
Bay Area Research Group

ACOT Report #12

Apple Computer, Inc.
20525 Mariani Avenue
Cupertino, CA 95014

Researc

The Study

ACOT's evolution is rich with information about the potential for innovative relationships between business and education.

Businesses are looking for ways to assist in the transformation of education.

ACOT focuses on learning and teaching—a rarity in business-education partnerships.

Begun in 1985, Apple Classrooms of Tomorrow (ACOT)℠ is a research and development collaboration among public schools, universities, research agencies and Apple Computer, Inc. ACOT explores, develops and demonstrates the powerful uses of technologies in teaching and learning. In all ACOT endeavors, instruction and assessment are as integral to learning as technology.

Supporting a constructivist approach to learning, technology is used as knowledge-building tools. As students collaborate, create media-rich compositions and use simulations and models, researchers investigate four aspects of learning: tasks, interactions, situations and tools. The research is formative. The findings guide ACOT staff and teachers as they refine their approach to learning, teaching and professional development. ACOT teachers and students often use the most advanced technologies available, including experimental technologies, to help us envision the future and improve the educational process.

ACOT views technology as a necessary and catalytic part of the effort required to fundamental restructure America's education system. We hope that by sharing our results with parents, educators, policy makers, and technology developers the lessons of ACOT will contribute to the advancement of educational reform.

This paper is based on visits to four ACOT sites in the spring of 1990 and interviews with Apple ACOT staff—the first round of a three-year study for Apple Computer, Inc. about the role of ACOT in educational restructuring. The author draws on her earlier involvement in studying ACOT in its first year of operation and on her current work on restructuring for the National Governors' Association and the National Center for Education and the Economy.

Since its inception in 1985, the Apple Classrooms of Tomorrow project has established a community of partners with school districts and researchers across the United States. The evolution of ACOT provides a rich source of information about the potential for innovative and productive relationships between business and education. It is a story of experimentation, not simply with technology and learning, but also with the creation of research laboratories inside school systems, the role of an external change agent, and the development of a mutually satisfying collaboration.

The topic is particularly timely given heightened national concern about the capacity of the public school system to produce qualified graduates, and a corresponding shift in how the private sector views its relationship to public education. Education leaders and policy makers nationwide are embracing the need to restructure the public education system in order to improve student performance, and many businesses are looking for ways to assist in this transformation.

ACOT began as a technology-saturation model with straightforward quid pro quo relationships with school districts.

Through The Business Roundtable, 200 executives from the nation's largest corporations made a 10-year commitment to assist state governments in the process of restructuring. But they noted an absence of model partnerships:

> *There are no readily applied or general models for business in helping educators restructure or renew education. The companies of The Business Roundtable and the other companies that need to get involved in this crucial effort are on the cutting edge of a new kind of business involvement in our nation's schools. They will be exploring for the first time how business can help effect fundamental education change.* (National Alliance of Business 1990)

Experience changed the nature of the partnerships.

ACOT does not tackle all the issues around new forms of business involvement in education; for example, it does not attempt to directly influence state policy or district management practices. Instead, ACOT focuses on teaching and learning—a rarity in business-education partnerships. Apple staff and their research partners work directly with teachers and students on issues of curriculum, instruction, technology, staff development and assessment.

ACOT provides a model of partnerships characterized by continuous learning and the ability to change and adapt on both sides. ACOT's experiences offer valuable guidance to businesses, districts, schools, and researchers alike as they form new alliances to promote education change.

Responding to learning and research needs, ACOT staff played a more directive role with a goal of transforming teaching and learning.

[illegible] ACOT Partnerships

ACOT began as an experiment about the effects of computers on education: What happens to teaching and learning when every teacher and every student have two computers—one at school and one at home? Instead of setting up an artificial laboratory situation, the ACOT staff wanted to study computer saturation in real-world classrooms which represented a range of settings and student populations.

The ACOT partnerships began as straightforward quid pro quo relationships with several school districts. Apple provided equipment and technical support, and districts supplied teachers and students willing to experiment with technology, report on their experiences, and be available for study by Apple and Apple's consultants.

ACOT supports longitudinal and experimental studies.

As the ACOT participants gained more experience, the nature of the partnerships changed. The tendency of educators to incorporate technology only into existing practices, the absence of curriculum and software built around interactivity, and the difficulty of measuring learning outcomes beyond factual knowledge all influenced ACOT's strategy. In response, the ACOT staff chose to play a more directive role with the explicit goal of transforming teaching and learning.

Schools, university-based researchers and ACOT are an integral team.

Today, ACOT supports two kinds of partnerships. The first — and the main focus of this report — are the Longitudinal Research Centers (LRCs). ACOT established long-term relationships with three schools, an elementary, middle and high school, in order to work with the same teachers and students for a sustained period of time. Each of the three sites also works closely with university-based researchers.

The second kind of partnership, the Experimental Learning Centers (ELCs), consist of more than two dozen research projects, each with a classroom teacher, developer and researcher. These are short-term projects, typically three years maximum, designed to solve particular issues that arise in the LRCs. For example, teachers in the ACOT LRC high school found that physics students were having more trouble with the algebra associated with physics than with the physics concepts. This spawned a research and development effort with NASA and the University of Houston, which were developing an "intelligent physics tutor," to address the students need for better problem solving skills.

Apple Computer and the three LRC school districts each make substantial contributions and commitments to the partnerships. Apple provides computer equipment and electronic

Both schools districts and Apple fund technology and human resources with these investments yielding considerable benefits to both partners.

Apple gets real-world laboratories to develop and test new knowledge about teaching and learning.

School districts boast a cadre of teachers and students who are national experts in teaching and learning with technology.

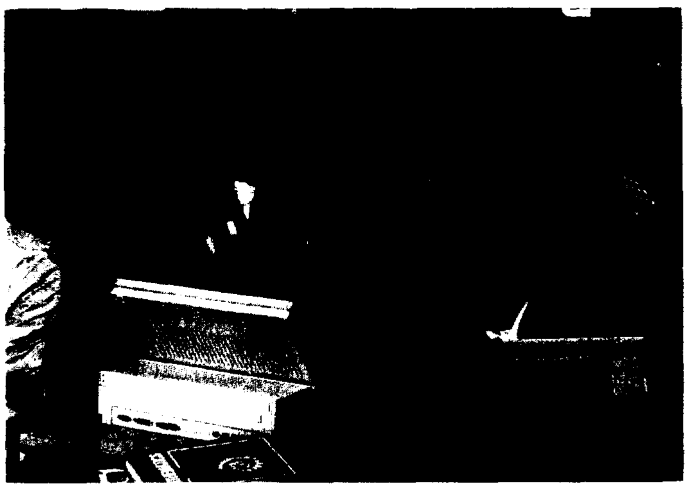
Teachers and administrators are learning what it takes to transform teaching and learning in a way that is consistent with the nation's education goals for the 21st century.

mail, training, on-site assistance, on-line availability for technical support, professional development institutes, curriculum development, assistance with publications, and sponsorships for conference attendance. In addition, Apple supports part or all of a coordinator position at each school, funds university-based researchers and facilitates links to software vendors.

In exchange, each district sets annual goals for curriculum development, instructional strategies, technology use, and student learning. Teachers and coordinators participate in a variety of research studies, and collect and report data on their activities, including weekly electronic mail reports and monthly audio tapes. They participate in conferences and other project activities, document exemplary lessons, review software, and host visitors and media observers. Each district also contributes financially by supporting part of a school or district coordinator, reducing the teaching load of participants, and allowing extra time for planning, conferences, meetings, and summer activities. Districts also contribute supplies (such as computer disks) and facility upgrades (telephone lines, wiring).

These investments yield considerable benefits to both partners. Apple gets real-world laboratories in which to develop, test, and generate new knowledge about teaching and learning in a context clearly separated from company profits. The school districts boast a cadre of teachers and students, who are becoming national experts in teaching and learning with technology. Beyond providing a valuable technical resource to their schools and districts, the Apple classrooms also bring positive publicity. Each site has appeared on national television and in published articles, and receives visitors from all over the world. Teachers and administrators are learning not only about technology in instruction, but also what it takes to transform teaching and learning in a way that is consistent with the nation's education goals for the 21st century.

The partners also benefit from the rich experience of a joint venture that has a strong commitment to strengthening education. The teachers and administrators have committed their professional lives to ACOT, typically spending 60 to 80 hours a week on their jobs, and maintaining a delicate balance of exhaustion and exhilaration. Apple staff members consider ACOT teachers their professional colleagues, and share a deep commitment to their well-being and professional growth.



Teachers and students roles change dramatically in ACOT classrooms.

Perceptions about technology's role shifted from a preoccupation with "computer literacy" to the use of multiple technologies as powerful learning tools.

The important notion that people learn by constructing knowledge actively through challenging hands-on activities gained prominence.

Much of the way schools are organized stands in the way of providing challenging learning tasks for students.

ACOT's original saturation model has changed drastically.

Students and teachers need different kinds of technology for different purposes.

The Education Context

When ACOT was first launched in the fall of 1985 the role of technology in education reform was seen much differently than now. During this period, perceptions about the appropriate role of technology in schools shifted from a preoccupation with "computer literacy" and programming languages to the use of multiple technologies as powerful tools for learning. At the same time, contributions from cognitive science and applied research on teaching and learning greatly expanded our understanding of how people learn. The important notion that people learn by constructing knowledge actively, through engagement in hands-on, challenging activities, and connecting new knowledge to previous experience — rather than by listening passively — gained considerable prominence.

Pressure to improve the public schools also shifted the debate from the top-down, add-on approaches of the past to the broader concept of organizational change throughout all levels of the education system. Signaled by the word "restructuring," this approach to education change is driven by the goal of increasing the performance of all students by creating stimulating learning environments. Restructuring requires changes in roles and responsibilities from the classroom, to state government and even to the federal level. But the barriers to change are many.

Inside schools, teachers and administrators need to learn new ways of doing their jobs. Teaching for understanding and thinking is much more difficult than teaching isolated facts, and few teachers were trained to teach this way. School structures—schedules, calendars, tracking, course credits—pose further constraints. Designed to promote content coverage rather than understanding, much of the way schools are organized stands in the way of providing challenging learning tasks for students.

Shifts must also occur at the district level. The way most districts organize staff development does not create the kind of learning opportunities teachers need. District staff are trained to generate and enforce rules, not to foster school improvement and provide or broker the assistance schools need. Studies of what it takes for schools to change significantly suggest four critical elements: an invitation to change, the authority and flexibility to do things differently, access to knowledge, and time. Few districts are currently able to provide these conditions, especially in the absence of supporting state policies.

This is the arena within which ACOT has taken on the transformation of teaching and learning. Committed to the belief that technologies are powerful tools for learning that can empower students and enhance their understanding, ACOT and its partners embarked on an untraveled path. For both, the learning curve has been and continues to be steep.

When ACOT was first established, Apple held assumptions about access to technology and about grass roots change which reflected its own internal philosophy of the early 1980s. These assumptions were quickly put to the test and revised accordingly.

Access to Technology: A New Definition

When ACOT began in 1985 at three sites, Apple's conception of access to technology was a computer on every student's desk at school, and one at home to make the technology as readily available as other basic tools for learning, from pencils to books. But the realities of the classroom and the continual evolution of the technology have led ACOT staff to conclude that students and teachers need different kinds of technology for different purposes. Many instructional situations do not require any electronic technology. Moreover, students

Notebook computers that students carry and multimedia computers capable of desktop publishing and simulations will play a large role in future classrooms.

Teachers naturally tend to incorporate technology into their existing practices and styles.

Transforming classrooms into stimulating environments requires a fundamental change in the culture of schools.

ACOT is exceptional in that teachers have discretion over their curriculum and instruction.

need physical space for using other materials. ACOT staff also found that 30 computers in a room can force teachers back into predominantly whole class instruction; fewer computers are more likely to force different organizational arrangements.

The optimal configuration of technology will vary by classroom and over time as technology changes. For the future, ACOT envisions a combination of different technologies: inexpensive notebook computers that students carry with them, and a small number of multimedia stations capable of desktop publishing, simulations, presentations, and other uses that demand more powerful and versatile equipment.

ACOT staff also recognized a need for educators to better understand the capabilities and appropriate uses of a variety of computers. Although newer, easier to use and more powerful machines may always be preferable, schools will never be able to afford a large number of the very latest models. Older computers may not be appropriate for all purposes, but may well be suited to a few general tasks, such as word processing, the most common use by students and teachers.

Changing Classroom Practices

At the beginning of the project, ACOT staff also assumed that the presence of an intensive technology environment would spur dramatic changes in classroom practices. They discovered, however, that their images of the role of technology in instruction were not necessarily shared by the teachers. Certain changes were inevitable due to the new physical arrangement of a computer for each student in the classroom, but new approaches to instruction did not necessarily follow. In fact, teachers naturally tended to incorporate technology into their existing practices and styles. Consequently, the ACOT staff balanced their emphasis on the uses of hardware and software with an aggressive effort to introduce new ways of teaching and organizing instruction.

The image of classrooms as stimulating learning environments—in which students are actively engaged in solving challenging problems both as individuals and as team members—is a far cry from traditional classrooms. Among many barriers to change, teachers are not trained to organize instruction in ways that actively engage students; class periods are too short for in-depth problem solving; materials are geared to superficial coverage of vast amounts of information instead of understanding; and few teachers and students are accustomed to working in teams.

Transforming classrooms into stimulating learning environments requires a fundamental change in the culture of the school. The teacher's role changes from delivering information to facilitating student learning — more coach and manager than lecturer and sole source of information. Teacher collaboration replaces teacher isolation, and students also begin to work more collaboratively. As noted above, such transformation requires an invitation to change, the authority and flexibility to do things differently, access to knowledge, and time. Ultimately, for change to occur beyond individual classrooms, these conditions must exist systemwide.

For a single classroom, however, ACOT does provides an invitation to change. Because ACOT is an exceptional and experimental environment, teachers tend to have considerable discretion over their curriculum and instruction, (within district and state requirements), and more time for planning. ACOT's major role, however, is in providing access to new knowledge. Through experience in the classroom with ACOT teachers, Apple staff saw the

The teacher as learner is key to creating a new culture in the classroom.

Traditional forms of staff development for teachers do not help.

Collegial interaction and time to plan and improve their practices dramatically alter teaching methods.

need to expand their role as directors, providers and brokers of a broad range of learning opportunities.

The teacher as learner is key to creating a new culture in the classroom. However, traditional forms of staff development for teachers do not help. Teachers, like students, learn when they have on-the-spot access to help, models to learn from, other teachers to observe and be observed by, colleagues to share and discuss ideas with, as well as more opportunities to learn outside the classroom.

ACOT has provided opportunities for teacher learning that rarely exist in school systems. Apple staff visit each classroom several times a year, spending several days on site working directly in the classroom with teachers. Teachers learn from on-site expert help, and Apple staff learn what is and is not possible in a classroom setting. University researchers working in the classroom provide new knowledge to teachers, and in turn, have an ideal setting in which to pursue questions about teaching and learning with technology.

All the sites are on AppleLink, an electronic mail system, enabling direct communication with Apple staff and other ACOT schools on a daily basis. Apple brings in all the site staff each summer for a one week intensive institute staffed by experts in such areas as student portfolio assessment, thinking creatively, and project-based instruction. ACOT teachers are encouraged and supported by Apple staff to share their experiences in presentations at education conferences, providing an opportunity for professional interaction not often available to teachers.

ACOT teachers describe their experiences as challenging, difficult, frustrating, and incredibly rewarding. Teachers who have remained with ACOT for several years comment that the experience "challenged me in ways I've never been before" and the "thrill of teaching came back."

Observations of ACOT classrooms demonstrate that major change has occurred in sites with several years' experience. The rooms look quite different, partly because they are filled with technology, but also because teachers and students are playing different roles. There is considerable interaction as teachers and students together ask and answer each others' questions. According to interviews with teachers, the way they plan, organize, and deliver instruction has changed significantly. (See Figure 1.)

Changes in Teaching in ACOT Classrooms

- More project oriented work
- More extensive projects
- More group work and cooperative learning
- More individualized attention
- More interdisciplinary activities
- Giving students choices
- Great reduction in of lecturing
- Elimination of worksheets
- Different philosophy of teaching
- More efficient drill and practice
- More motivation for writing process
- No more 'teach a skill, test a skill'
- More learning centers
- Far less correcting papers
- Joint planning with colleagues
- More ways to get information—unlimited with modem
- Introduction of student portfolios
- Less structured classroom—students more independent
- Faster lesson preparation and revision on computer

Figure 1: *Teachers reported changes in their practice.*

Concentrating resources was essential to learn what's possible, but it meant trade-offs.

Other faculty envy ACOT teachers who have more preparation time, resources, space, and support.

The school's principal can make a big difference in how ACOT is perceived by the faculty.

Because schools aren't familiar with research and development, they can misjudge the value of an experimental situation.

Classrooms and the School Culture

The classroom was ACOT's original focus. This choice stemmed in part from their belief in bottom-up, grass roots change, and in part from their definition of access to technology. The substantial cost of providing every student and teacher with two computers precluded serious consideration of equipping an entire school. The role of district and school administrators was primarily limited to contractual and budgetary issues.

A clear benefit of the choice to focus on one or two classrooms is the ability to concentrate resources — hardware, software, as well as training and assistance — on a small number of teachers and students. Such a concentration of resources seemed essential to learn what is possible under conditions that may well be prevalent in years to come.

It also meant trade-offs. Creating a "special" classroom inside a school has the effect of separating it from the rest of the school. When the special classroom has considerably more resources than other classrooms and no clear benefits to other faculty, the perceived gulf is even greater. This is especially the case in schools that have not had much experience with research and development activities. As a result, other faculty envy ACOT teachers who have extra preparation time, more space, and considerable technology at their disposal. These differences are exacerbated by the restrictions of some software vendors which prevent the sharing of software.

According differential status to some teachers and students is more likely to succeed when all have had an equal chance to participate. ACOT sought teacher volunteers and required a fair, nondiscriminatory selection process for students. Nevertheless, not all interested teachers were able to participate, and student selection was somewhat biased towards those whose parents took action in volunteering their children. Problems also arise when an innovation is introduced in ways that do not match existing organizational arrangements in the school, for example, an ACOT classroom restricted to one grade level in a school organized by ungraded teams. The school's principal can make a big difference in how ACOT is perceived by the faculty, if he or she has had an opportunity to buy into and support the enterprise.

Apple ACOT staff initially believed that the activities in ACOT classrooms would spread to other classrooms over a period of several years. Experience suggests that this model of change is not likely, at least under existing school organization. Consequently, ACOT's newest LRC site represents a different model of change. Instead of one classroom at a time, ACOT staff are experimenting with a whole-school approach. The goal is to work with teams of teachers, moving the technology and professional development activities to a new team every few weeks. By the end of the first year, the whole faculty will have been exposed to technology and training and prepared for more extensive use the following year.

The long range of goal of the ACOT research and development agenda is to recommend ways in which hardware and software maximize active learning.

Relevant lessons are not the kinds of immediate "answers" educators tend to seek.

Needs of researchers and needs of teachers and students don't always overlap.

Research and Development in School Systems

Research and development is a familiar concept to the private sector. Consequently, Apple staff presumed research and development projects would also be familiar to schools and districts. Because it is not, both school and district staff can easily misjudge the value of an experimental situation. Educators look at ACOT and dismiss it as unrealistic because of the concentrated resources. They conclude that because it is not replicable as is, it has minimal relevance for the school or district. Those who look to ACOT for results tend to want firm answers quickly, which is not always possible given the long term nature of the experiment, and the complexity of the questions.

The long range goal of ACOT's research and development agenda is to recommend directions for hardware and software development that will maximize active learning. ACOT is particularly interested in three research strands. The first is the creation of tools that provide media-rich composition environments, enabling students to express themselves via text, graphics, sound, animation, video. The second is analogous to workgroup software in business—software that enhances collaborative work among teachers, students, and across distances. The third is simulation software, some of which utilizes artificial intelligence to monitor and guide students as they explore and build, and prevents the common problem of students' drawing erroneous inferences without feedback to alert them.

The notion that there might be useful knowledge being generated that has implications for district decisions on curriculum, instruction, grouping, technology, assessment, and staff development is rarely appreciated by educators for two reasons. One is that the relevant lessons are not the kinds of immediate "answers" educators tend to seek. The other is that ACOT does not focus on the implications of these intermediate lessons for district policy. Policy makers pay attention to information when it is relevant to a particular decision under consideration and is in terms they can readily understand. Influencing education policy requires an awareness of the kinds of decisions district leaders make and an ability to extract and communicate the lessons that are relevant in appropriate ways.

Communication is critical in the process of change. Communication to local policy makers can range from presentations to the school board to research summaries designed for district and school administrators. Keeping the multiple audiences involved in education aware of findings—both problems and successes—is essential for maintaining support for continued experimentation and change. Ultimately, educational change requires broad-based support. Direct participants in ACOT are a strong base of support, but they are only a small percent.

The research and development component of ACOT also raises interesting questions about the appropriate role of researchers in classrooms—an issue which is becoming important as the appeal of professional development or practice schools grows. These are envisioned as whole schools created with many of the same goals as ACOT: creating dramatically different learning environments for students, conducting research on the process of change and on teaching and learning, and providing a stimulating environment for training new teachers.

The needs of researchers and the needs of students and teachers do not always overlap. Tensions can arise within a classroom if the research is particularly intrusive. Problems can also arise across classrooms if the research agenda requires participation of some students and teachers and not others, or if product testing or other research agendas take time away from required activities and curricula. ACOT teachers and students are not immune to the myriad of local, state, and federal requirements that dictate much of what goes on in classrooms from textbooks to tests. Clear communication among the parties involved lessens these potential conflicts considerably. ACOT teachers want to cooperate with research agendas but are not in a position to resolve conflicting directives from multiple parties.

Clear communication lessens potential conflicts considerably.

Finally, ACOT as a high-technology experiment attracts many visitors — educators, researchers, and the news media, among others. As with any cutting edge experiment, there is a difficult trade-off between sharing knowledge with the public and protecting the time and energy of the participants. For ACOT teachers and students, the combination of multiple research projects and visitors leads to high volume traffic. On the other hand, most acknowledge that participation in research is a valuable learning opportunity; and hosting visitors creates a sense of pride and confidence that is invaluable.

ACOT partnerships are not only designed to significantly change how schools operate, but they aim to do so by working directly with teachers in the classroom.

Tensions between Business and Education

ACOT partners have encountered some tensions that are inevitable when business and education work together. In addition to dramatically different cultures, school districts and corporations operate on different calendars, with different fiscal years and accounting procedures. These differences have implications for funding cycles, arrival of equipment, assignment of staff, and a variety of other decisions critical to the smooth functioning of ACOT.

For example, Apple's proposal development timeline requires proposals from districts as the school year ends. Consequently, when Apple needs final sign-offs from districts, the school board is not in session. On the district side, the fact that it is impossible to predict enrollment precisely before school starts is difficult for business to comprehend. Corporate decision makers are accustomed to a much more predictable and controllable environment.

Tensions are inevitable when business and education work together.

Another major operational difference lies in annual review cycles. Businesses typically review commitments annually, which has the potential disadvantage of frequent change but the advantage of providing an opportunity each year to "sell" a project internally and thereby strengthen the commitment of executives to the project. In school districts, once a project has been accepted and funded, it is likely to be on automatic pilot; only if a problem arises will the original decision be reconsidered. Moreover, the project becomes an entity unto itself and is unlikely to be taken into consideration in other policy decisions that might influence it. Such fragmented decision-making typifies school districts, where multiple funding sources, each with their own multitude of rules and regulations and associated bureaucracy, do not facilitate strategic planning and coordinated decision making.

If a business is perceived as caring more about its product than about teachers and students, it cannot become an effective partner.

ACOT partnerships are different from typical business-education partnerships.

Technology's role has shifted from "computer literacy" to powerful learning tools.

Perhaps the biggest challenge for business involvement in education concerns trust—creating a balance between the interests of both parties. Educators are often distrustful of business involvement because they assume their real agenda is selling a product. If business is perceived as caring more about its product than about the teachers and students, it cannot become an effective partnership. When schools get something in return, this is perceived as reasonable—each side must get something out of the partnership. But when the purpose of

This kind of endeavor requires a much deeper understanding of how both sides operate, their intentions and abilities.

Partnerships must be based on shared goals.

Business must demonstrate that share goals are more important than self interest.

business involvement is to change the status quo, both sides must buy into the same goal. There must be a genuine give and take which can only occur when trust has been established over a period of time.

During ACOT's history, perceptions on both sides changed significantly. An important turning point was a shift from perceived exploitation of the classrooms for Apple marketing purposes, to a clear signal from Apple that ACOT's purpose was long-term research and development aimed at producing new knowledge about technology and education. Sites no longer relied on local Apple sales representatives as their main source of assistance; nor were they asked to participate in surveys or other studies designed to provide fodder for sales and marketing units in Apple. As a result, participants shifted from viewing ACOT as simply an opportunity for free equipment to developing a sense of responsibility for sharing in the research and development enterprise.

From the business side, Apple staff encountered the realities of public schools: like teachers they have little control over staffing, curriculum, schedules, and testing. They also face frequent turnover of key players. Those who negotiated and approved the original agreement, often including the school board, superintendent, central office, and school staff — as well as teachers — have a high turnover rate. Urban superintendents have an average tenure of three years. School board members, who approve all contracts, are up for re-election frequently. These circumstances make long-term commitments difficult and help explain the fact that long-term projects often persist by default than regularly reaffirmed commitment.

The kinds of partnerships represented by the ACOT sites are different from typical education-business partnerships. Not only are they designed to significantly change how schools operate, but they aim to do so by working directly with teachers in the classroom. Even partnerships designed to improve schools, like the Boston Compact, do so through external incentives such as commitments for job placement or assistance at schools through tutoring and mentoring. These approaches carry some benefits, but cannot alone change what happens inside classrooms. In contrast, ACOT provides intensive training and support to teachers, albeit small in number, to actually change the way they do their jobs.

This kind of endeavor requires a much deeper understanding on both sides of the others' modus operandi, intentions, and abilities. If the relationships are not built on trust and long-term commitment, they cannot succeed. For Apple, establishing ACOT as a research and development project was a critical step in creating trust and credibility. That trust was reinforced by the instructional expertise and sensitivity of the Apple staff who work with the sites.

ACOT staff walk a delicate line: pressing for fundamental changes in teaching and learning, but not dictating to teachers. The sentiment of ACOT teachers across the sites reflects this challenge: "Business involvement is OK as long as they don't tell us what to do." Apple's ACOT staff successfully moved into a more directive role without going too far.

Companies less directly involved in educational products might have more difficulty creating an in-house staff with educational expertise. However, they could follow the model of ACOT's brokering role in research and development activities by supporting a cadre of consultants knowledgeable about teaching, learning, and organizational change. On the other hand, this kind of intensive collaboration is, by its nature, limited to a small number of participants, and Apple's ACOT staff constantly question whether they can have an impact beyond their size.

School districts must provide the conditions needed to nurture experimental settings.

School districts must demonstrate an openness to apply the lessons learned.

On-going communication of important lessons learned by all partners is critical. Without it, the concept of research and development won't take hold in schools.

Beyond appropriate staff and sensitivity to the differences in culture, both corporations and school districts share responsibility for making a partnership for change successful. The ACOT experience suggests some important conditions that can only be created with cooperation from both parties:

- Partnerships must be based on shared goals and commitment from all levels of the school system—district leaders, school leaders, and ACOT participants. The commitment must be reaffirmed frequently, especially as leaders leave and are replaced.
- The business partner must demonstrate that self-interest does not override the goals of the partnership.
- The district partner must provide the conditions needed to nurture an experimental setting, and the openness to apply the lessons learned.
- Partnerships created to affect teaching and learning require extra time for teachers and intensive professional development—whether or not technology is involved.
- Innovations must mesh with existing organizational structures. Unless there are compelling reasons otherwise, any intervention should treat the whole school as the unit for change.
- Flexibility is key—for teachers to work together, to change schedules, to experiment, and for all sides of the partnership to learn and adapt continuously.
- Clear lines of communication are critical. Business partners must understand that relationships and communication among levels in school systems are very different that in business, and must ensure that teachers do not receive contradictory messages.

Research and development—on teaching and learning, on what it takes to change teaching practices, on uses of hardware and software, on new forms of assessment—is becoming more important to school systems as efforts to restructure break new ground. Beyond the occasional pilot project designed to test a particular method or approach, very little research and development occurs inside school systems, largely because there is no financial support, little flexibility to experiment, and no mechanism to learn from experiments. ACOT demonstrates that corporations, in concert with educators, can make significant contributions in this arena.

To ensure that a small experimental effort has implications beyond the classroom walls, all parties must understand who needs what kind of information in what form. Without extraordinary effort on the part of local educators and policy makers, business partners, and researchers to observe, translate, and communicate important lessons in on-going fashion, the concept of research and development will not take hold in school systems.

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APPLE CLASSROOMS OF TOMORROW

The Relationship Between Technological Innovation and Collegial Interaction

Authors
Judith Haymore Sandholtz Ph.D.
University of California, Riverside
Cathy Ringstaff Ph.D.
David C. Dwyer Ph.D.
Apple Computer, Inc.

ACOT Report #13

Apple Computer, Inc.
20525 Mariani Avenue
Cupertino, CA 95014

Research

The Study

Constant access to technology influences the frequency, form and substance of teachers' collegial interaction.

Begun in 1985, Apple Classrooms of Tomorrow (ACOT)℠ is a research and development collaboration among public schools, universities, research agencies and Apple Computer, Inc. ACOT explores, develops and demonstrates the powerful uses of technologies in teaching and learning. In all ACOT endeavors, instruction and assessment are as integral to learning as technology.

Supporting a constructivist approach to learning, technology is used as knowledge-building tools. As students collaborate, create media-rich compositions and use simulations and models, researchers investigate four aspects of learning: tasks, interactions, situations and tools. The research is formative. The findings guide ACOT staff and teachers as they refine their approach to learning, teaching and professional development. ACOT teachers and students often use the most advanced technologies available, including experimental technologies, to help us envision the future and improve the educational process.

ACOT views technology as a necessary and catalytic part of the effort required to fundamental restructure America's education system. We hope that by sharing our results with parents, educators, policy makers, and technology developers the lessons of ACOT will contribute to the advancement of educational reform.

This study examines how teachers already enjoying collegial interaction are able to implement new technology and instructional strategies more quickly.

The adoption of innovation and the creation of a collaborative environment are complementary conditions for change.

This report examines the process by which an immediate-access-to-technology environment influences the frequency, form and substance of collegial interaction among classroom teachers. The study covered a five year period, utilizing data from 32 elementary and secondary teachers in five schools located in four different states. Over time, teachers' interactions moved from informal, infrequent exchanges to structured technical assistance to formalized team teaching. However, the process of building collaboration was lengthy, involved overcoming numerous obstacles, and varied for elementary and secondary teachers.

> *Technology clearly has the potential to vastly transform relationships between teachers and students and even what schools look like. However, the history of education reform provides scant evidence that such a transformation will occur simply because the technology exists. Schools have demonstrated an unyielding resistance to change over the decades. Reforms that are adopted tend to be those that readily fit existing organizational structures and practices. (David, 1990, p. 76)*

The effective use of technology in elementary and secondary school classrooms is often a slow process marked by a variety of obstacles, and one of the key obstacles is a condition common in many schools: teacher isolation.

This report examines how technology-rich environments, like the Apple Classrooms of Tomorrow, influence and encourage collegial interaction among teachers, and how teachers who already enjoy a high level of interaction are able to implement new technology and instructional strategies more quickly. The adoption of innovation and the creation of a collaborative environment are complementary conditions for change, and constructive

Previous research indicates teacher interaction in effective schools tends to be frequent, task focused and widespread.

change occurs most quickly in environments where these two conditions are operating simultaneously.

The nationwide movement toward restructuring schools acknowledges that innovations introduced at only one level of a system are not likely to succeed, and that lasting change will not occur simply by giving teachers the latest technological tools. Teachers must be provided with on-going support which is available only if the larger system in which they are working changes as well. The reduction of teacher isolation is an important part of that change.

Research on Collegial Interaction and Innovation

For teaming to work, teachers need long-term assistance.

Researchers have identified regular opportunities for interaction with colleagues as an important feature of a successful work environment (Purkey & Smith, 1983). Teacher interaction in effective schools tends to be frequent, task focused, and widespread (Little 1982; Rutter, Maughanm Mortimore & Ouston, 1979). However, in many schools, opportunities for interaction are limited and communication tends to be informal and infrequent, even though teachers believe their teaching could be improved by working with colleagues (Corcoran, 1988).

Teacher change evolves over time only after technology proves to help them in their teaching.

Attempts to increase teacher interaction typically involve creating formalized team teaching arrangements, sometimes across grade levels and disciplines. These changes in school structures increase the incidence of collaborative teaching and the overall amount of task-related communication (Charters, 1980). However, teachers are reluctant to sustain team allegiance over time (Charters, 1980) and need long-term assistance in order to make teaming work effectively and efficiently (Rutherford, 1981).

Thirty-two ACOT elementary and secondary teachers were studied for five years. Computers were used as tools and didn't replace other materials or technologies.

Innovation can be extremely difficult to institutionalize because homeostatic forces in schools are more powerful than innovative forces (Joyce, 1982). Teachers may also resist change because the innovation comes from policy makers or non-teaching experts (Butt, 1984; Common, 1983). Serious commitment to innovation occurs only after teachers see that it really does assist them in teaching their students (Gersten & Guskey, 1985). However, this type of change does not occur quickly, but evolves over a period of time (Dwyer, Ringstaff & Sandholtz, 1990; Gersten & Guskey, 1985). In addition to identifying time as a critical resource, researchers point to the importance of a supportive organizational environment and collegial sharing in moving teachers toward the adoption of innovations (Educational Technology Center, 1985; Joyce, 1982; Henson, 1987).

This paper links these two areas of research by examining the relationship between collegial interaction and technological innovation. During the five years this of study, the symbiotic relationship between innovation and teacher collaboration became increasingly apparent. As innovation was introduced and adopted, teachers interactions moved from informal infrequent exchanges to structured technical assistance and finally to team teaching.